Low Power All-Optical Wavelength Conversion with Terahertz Refresh Rates using Colloidal Nanocrystals

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Owing to their widely tuneable optical properties and strong light-matter interaction, colloidal quantum dots[1] (QDs) are considered for next-generation photonic devices such as solution processable lasers[2] and all-optical wavelength converters. Using QDs for this last application, *i.e.* wavelength conversion, is limited by either slow interband (10^6-10^9 s^{-1}) or energy consuming multi-exciton dynamics (10^9-10^{12} s^{-1}). Here we show, using white light pump-probe spectroscopy, that the interplay between two intrinsic material properties of PbS QDs, intraband absorption and interband bleach can lead to a very strong modulation of near-infrared light on an ultrafast, picosecond, timescale: A peculiar dynamic arises at the matching wavelength: a strong burst of absorption induced by the pump lasts for roughly 1 picosecond and vanishes, leaving the dots as they were before the pump pulse arrived.

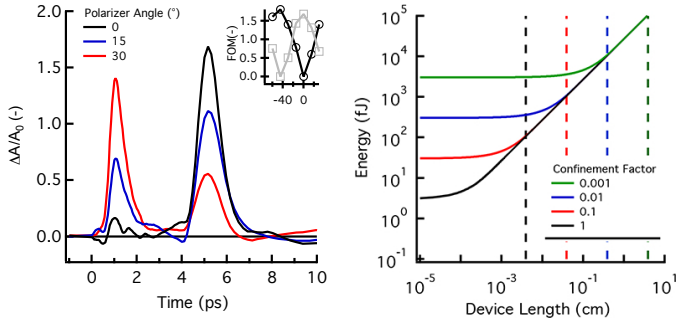

Figure 1: (left) Normalized absorption change (FOM) of probe after 180 fs pulse input sequence showing 225 Gb/s all-optical wavelength conversion and (right) Energy per bit (in femtojoule) for switching as function of device length (in cm) for QD enabled silicon waveguide with different modal confinement factors.

This provides an excellent platform to convert wavelengths without residual absorption, high conversion efficiency and picosecond speed. To characterize the conversion, the normalized absorption change ($\Delta A/A_0$) is chosen as a figure-of-merit (FOM): reaching up to 23 for a single exciton population, both in colloidal solution and thin film, we deduce the strength of the absorption burst as 5200 cm^{-1}. To show the potential for high speed conversion, a pump pulse sequence of up to 4 femtosecond pulses, separated by 2.2 and/or 4.4 ps, is converted to a probe wavelength while preserving the intrinsic strength, speed and zero background of the single pulse case, showing the ability for handling 450 and 225 Gb/s datastreams. Combining the QDs with on-chip or fiber based devices is shown viable with conversion energies as low as a few femtojoule per bit with device footprints of a few hundred micron, much smaller than existing approaches.

References

[1] Y. Yin and P. Alivisatos, "Colloidal nanocrystal synthesis and the organic-inorganic interface.," *Nature*, vol. 437, no. 7059, pp. 664–70, Sep. 2005.

[2] C. Dang, J. Lee, C. Breen, J. S. Steckel, S. Coe-Sullivan, and A. Nurmikko, "Red, green and blue lasing enabled by single-exciton gain in colloidal quantum dot films," *Nat. Nanotechnol.*, vol. 7, no. 5, pp. 335–339, Apr. 2012.

[3] B. De Geyter, A. J. Houtepen, S. Carrillo, P. Geiregat, Y. Gao, S. Ten Cate, J. M. Schins, D. Van Thourhout, C. Delerue, L. D. A. Siebbeles, and Z. Hens, "Broadband and Picosecond Intraband Absorption in Lead-Based Colloidal Quantum Dots.," *ACS Nano*, vol. 6, no. 7, pp. 6067–6074, Jun. 2012.